Chapter 9

Bird Ecology as an Indicator of Climate and Global Change

Wolfgang Fiedler
Max Planck Institute for Ornithology, Department Vogelwarte Radolfzell, Germany

1. INTRODUCTION

Birds are highly mobile and easy to observe. They are relatively easy to recognise and their occurrence and habits are noted by millions of passionate birdwatchers or just interested laymen. It is not surprising that changes in abundance or behaviour of birds are among the best documented changes known in the animal world. Changes in the arrival of migrating birds at their breeding grounds and their disappearance in autumn have been used as cues to forecast weather in many cultures for centuries. Modern biology understands bird behaviour not as a result of miraculous wisdom of individuals but as a result of the action of evolution through mutation, selection and reproduction. Since a central goal in evolution is adaptation to the environment, climate change, as well as global change in a wider sense will change selection pressures and reproductive success of various behavioural types. This is, indeed, what is presently being observed and birds show us that we are already in the middle of massive changes.

However, it is important to note that not all changes in bird behaviour, as they are currently observed, can be attributed to climate change. Other factors, such as changes in land use, can influence the migration behaviour of birds. Changes in agriculture, in industrial activities or in human behaviour may offer or destroy suitable wintering sites. Examples include a new food source for European Cranes *Grus grus* in fields of winter weed in northern France, ice-free waters for Coots *Fulica atra* due to power plant cooling in Lithuania or bird feeders for Blackcaps

Climate Change: Observed Impacts on Planet Earth

Sylvia atricapilla wintering in Great Britain [1]. Effects can be accelerated or attenuated by climate change and in some cases it will not be possible to identify the primary source of change that affects a certain behavioural modification. Nevertheless, all of the environmental changes currently experienced, that top the list in terms of speed and extent, are very likely a result of human activity and thus share a common source. In this chapter, it will be shown that environmental changes affect all areas of a bird's life and that many indicators of this change can be found by observing birds and their ecology.

2. INDICATORS OF CHANGE

2.1. Range

2.1.1. Size and Position of Breeding Ranges

Changes in the distribution of birds, especially in their breeding range, were one of the earliest topics discussed among ornithologists in the context of climate change. Already in 1995, Burton [2] listed in his book 123 European bird species which extended their ranges in northern, western and northwestern directions and he attributed these changes to global warming. These observations meanwhile were supported by many other studies showing that range boundaries are moving poleward or upward in altitude as the climate gets warmer.

Sound data comes from comparing standardised breeding bird surveys. Such comparisons have been done on data from the United Kingdom and Ireland [5]. The comparison of the breeding bird atlas of 1968–1972 with the atlas of 1988–1991 showed that in 59 species with southerly distribution within the study area, there was a mean northward shift of their northern border of distribution of 18.9 km (see Table 1). This is equivalent to roughly a 1 kilometre northward shift of their northern range border per year. At the same time 42 northerly distributed species did not show any systematic movements of the southern border of their distribution area. In a comparable study with data from the time periods 1974–1979 and 1986–1989, it was found that the northern border of 119 southerly distributed species in Finland showed a mean northward movement of 18.8 km while the southern border of 34 northerly distributed species did not change [4]. Finally, data from the North American Breeding Bird Survey showed that 26 southerly distributed species moved their northern border of range on average 72.9 km northward between the periods 1968–1972 and 1988–1991 [3] while the southern border of northern species did not move.

Changes in breeding distribution registered, so far, are likely to be the first indications of rather severe ecological shifts and species rearrangements in some areas. Based on museum material of 1179 bird species and some mammal and butterfly species occurring in Mexico, ecological niche models have been developed with a genetic algorithm and were projected onto two predicted climate surfaces (conservative and liberal) for 2055. While extinctions

TABLE 1 Changes in borders of the range of bird species as revealed from breeding bird surveys

Region and source	Period 1	Period 2	Distribution within region	Number of species	Distance and type of shift	Shift/year
Great Britain and Ireland [5]	1968–1972	1988–1991	Southerly distribution	59	Northern border moved 18.9 km northward	ca. 1 $\text{km}\cdot\text{a}^{-1}$
			Northerly distribution	42	Southern border did not show systematic movements	
Finland [4]	1974–1979	1986–1989	Southerly distribution	119	Northern border moved 18.8 km northward	ca. 1.7 $\text{km}\cdot\text{a}^{-1}$
			Northerly distribution	34	Southern border did not show systematic movements	
North America [3]	1967–1971	1998–2002	Southerly distribution	26	Northern border moved 72.9 km northward	ca. 2.4 $\text{km}\cdot\text{a}^{-1}$
			Northerly distribution	29	Southern border did not show systematic movements	

and dramatic range losses were expected to be few, the turnover in some regions was predicted to reach more than 40% of the species [6].

The studies mentioned above lead to the expectation that in the first instance species richness should increase in areas with incoming southern species and northern species which have not left. Indeed, the Lake Constance area in Central Europe could be an example for this. Based on 2 × 2 km grid cells breeding birds in an area of 1212 km^2 were counted in a semi-quantitative way in the periods 1980–1981, 1990–1992 and 2000–2002. During this time species numbers increased from 141 to 154, in the last decade with a significant increase of species with a southern centre of distribution [7].

A flagship species for a northward range extension of a southerly distributed bird species in Europe is the Bee-eater *Merops apiaster*. Distributed mainly in

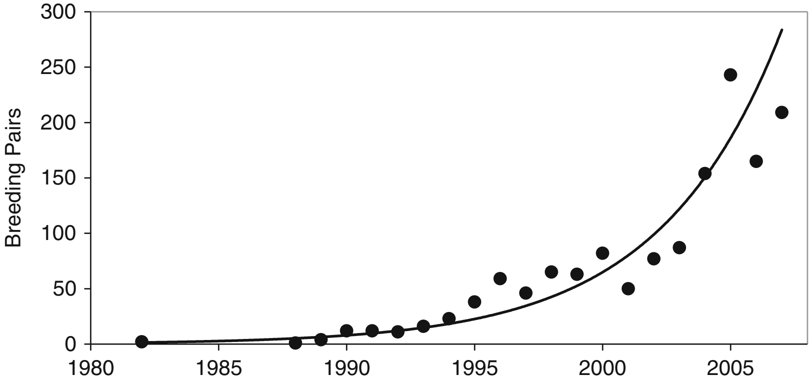

FIGURE 1 Number of breeding pairs of the Bee-eater *Merops apiaster* in the country of Baden-Württemberg (southwestern Germany) 1982–2007. Data from Boschert and Todte.

warmer areas such as the Mediterranean, the species starts breeding in higher European latitudes as soon as there are periods with warmer temperatures. This has been shown by a comparison between Bee-eater records in Central Europe and the size of growth rings in oak wood. The rings give evidence of warmer periods with higher annual growth rates in the oaks from the sixteenth Century onwards [8]. Currently, Bee-eaters are showing significant population increases (Fig. 1) and now breed as far north as Poland and Scandinavia.

On a European scale climatic variables in the actual breeding ranges of bird species have recently been used to forecast the future distributions based on the assumptions of first generation climate change models in the Climate Atlas of Breeding Birds in Europe [9]. This modelling leads to the prediction that between the two periods 1960–1990 and 2070–2100 breeding distribution areas of European birds shall move on average 550 km northwards and that many species shall suffer from area losses. This predicted value of a northward movement rate of 5.5 $\mathrm{km \cdot a^{-1}}$ is higher than has actually been found in the studies cited above.

One major problem with this approach is the lack of any account for habitat availability in Europe where many natural habitat types, due to human activity, will not be available, even when climate conditions would allow them to exist. This problem is not negligible as has been shown when bird distribution data from the breeding bird atlas of the United Kingdom and Ireland from 1968 to 1972 has been used to forecast the distribution in 1988–1991, using the same method as was used in the Climate Atlas of Breeding Birds [10]. The results were compared with real distributions in the second time period. For a series of species the forecasts did not match well and the real distributions were much smaller than the forecasted results. A remarkable example is the Red-backed Shrike *Lanius collurio* which in the 1970s was restricted to the South and Southwest of the United Kingdom. For the

1990s, models predicted a coverage of almost all of the United Kingdom, including the very north of Scotland. In reality, at that time, the species was almost extinct over the whole of the United Kingdom. However, two new breeding sites were established in Scotland, which was in accordance with the forecast.

2.1.2. Ranges during Nonbreeding Season

Besides breeding ranges, winter distributions are also changing. This is obviously the case where migrating birds can stay closer to their breeding grounds when closer areas become more suitable wintering areas for them, or when closer wintering areas become less suitable (e.g., dryer) and thus birds are forced to migrate longer distances [1].

Data from the Christmas Bird Count in North America between 1975 and 2004 showed a mean northward movement of the northern border of wintering ranges of migratory bird species of 1.5 $\mathrm{km{\cdot}a^{-1}}$. At the same time, winter distributions of non-migrants also moved northward during that time period [11].

In Europe, the effect of the drying-up of the Sahel belt, (a dry savannah area south of the Sahara desert where many Palaearctic long-distance migrants have their wintering areas), has been considered as one of the main reasons for population declines in the Common Whitethroat *Sylvia communis*, the Sedge Warbler *Acrocephalus schoenobaenus* and in many other species [12]. This indicates that the potential for rather simple latitudinal shifts of wintering areas, corresponding to changes in climate, is limited and might not be an option for all species.

2.2. Migration

2.2.1. Timing of Migration to the Breeding Grounds

Despite its complexity and genetic component, bird migration behaviour appears to be highly flexible and changeable in many species. Changes in migration behaviour have been and still are the subject of numerous publications. For example, in an impressive dataset from Finland, the arrival dates of birds at their breeding grounds have been recorded between 1749 and end of twentieth century [13]. After being quite stable or only moderately shifting up to the 1960s, the arrival dates since then have advanced by about a month in the case of the Skylark *Alauda arvensis* and about half a month for the Wagtail *Motacilla alba* and the ‘Swallows’ (Barn Swallow *Hirundo rustica* and the House Martin *Delichon urbica*), while the Cuckoo *Cuculus canorus* and the Swift *Apus apus* showed little change.

A recent analysis of banding data of birds passing the island of Heligoland in the North Sea during pre-breeding migration, for the time period 1960–2007, showed that Blackbirds *Turdus merula* and Pied Flycatchers *Ficedula hypoleuca* were now arriving 11 days, Willow Warblers *Phylloscopus trochilus*

13 days and Blackcaps *Sylvia atricapilla* 17 days earlier than they had before. The mean advancement of 24 species was 8.6 d for the total period or 1.9 d every decade [14].

Lehikoinen et al. showed in a related analysis [13] of 21 long term studies of 10 European countries a consistent advancement of arrival times at the breeding grounds for Sand Martin *Riparia riparia*, Blackcap, Chiffchaff *Phylloscopus collybita*, Wagtail, Barn Swallow, Pied Flycatcher, Sedge Warbler, Tree Pipit *Anthus trivialis* and House Martin. In contrast, Whinchat *Saxicola rubetra*, Spotted Flycatcher *Muscicapa striata* and Cuckoo *Cuculus canorus* did not advance their arrival times in half of the reported studies.

In a very large compilation of different studies in Eurasia, Sparks et al. [15] calculated an advance in arrival times of 2.5–3.3 $d{\cdot}K^{-1}$ warmer mean temperature.

The evidence for earlier arrival of birds at their breeding grounds in concordance with the warming up of the climate is enormous and corresponds well with the finding of a consistent global advancement of phenological events in spring between 2 and 5 d per decade [16]. However, some species react stronger than others to the advancement of spring phenology in certain regions and a few species seem unable to follow the changes. It was generally found that among 56 species in Lithuania, those species that arrive early in spring, advance their arrival dates more than those species arriving later in the spring [16]. There is, however, a variation in response on the individual level, but in general the first birds to arrive at their breeding grounds advance their arrival by four days per decade, while the mean arrival date (average arrival date of a population) advances only by 1 d per decade [16].

From an evolutionary point of view this indicates that some birds might benefit from an earlier arrival at their breeding grounds and thus show a strong response to changed environmental or climate conditions, while others change their timing at a much slower rate. One reason for the variation in the rate of changes within populations can be explained by the proximate factors driving the advancement of arrival times. The earlier arrival of Pied Flycatchers in recent years in southern Finland correlates well with higher temperatures in the winter quarters and along the homeward migration routes. However, the last birds to arrive did not advance their arrival dates, and late spring temperatures did not change [17].

In Europe, many studies used the North Atlantic Oscillation (NAO) [18] as a measure of climatic conditions. Almost all bird species in those parts of Europe influenced by the NAO, can adjust their homeward migration timing to rising temperatures. This seems to be true for long distance migrants (migration routes from Europe to at least sub-Saharan Africa) as well as for short distance migrants (migration between Europe north of the Alps and the Mediterranean). However, it seems to be necessary that birds experience the warmer temperatures not only after arrival at the breeding grounds but along migration routes and also in their wintering quarters. In Europe and North

America, birds do not arrive early at their breeding grounds if temperatures in these breeding areas rise but do not rise along the migration routes [19]. However, correlations between arrival times and temperature in the breeding areas have been found. In the long term dataset from Finland mentioned above [13] spring arrival times were clearly earlier in years with higher mean temperature in the month before arrival. Also in passing migrants, over the Courish Spit (Southern Baltic), a strong negative correlation between April temperatures and passage times of 20 songbird species has been observed [20].

Positive NAO values in Europe can mean not only warmer temperatures but poor conditions in the Mediterranean and Sahel zone. For example, Barn Swallows in Italy arrive later in years when there are poor conditions in Africa [21]. In Spain, an increasing delay in the spring arrival of migrants in the 1970s and a current return to the level of the 1940s has been found [22] despite increasing local temperatures. It has been assumed that this is an effect of poor conditions in northern Africa (mainly due to low precipitation), resulting in a poor food supply which in turn means a delay of fat deposition and consequently a later takeoff to the breeding grounds [23].

2.2.2. Timing of Migration from the Breeding Grounds

In contrast to the fairly consistent patterns of more or less pronounced advancements of spring arrival at the breeding grounds, when mean temperatures rise, the post breeding migration timing shows a very different picture. From a 42-year dataset of 65 migrating bird species, passing the Swiss alpine pass Col de Bretolet, the autumn passage of migrants wintering south of the Sahara has advanced in recent years, while migrants wintering north of the Sahara have delayed their autumn passage [24]. This advancement of post breeding migration timing in long distance migrants might be seen under the light of a selection pressure to cross the Sahel before its seasonal dry period. Species with shorter migration routes might benefit from a less constrained time schedule for breeding and moulting during summer when autumns are warmer and the risk of bad weather during autumn is reduced. This assumption is supported by the additional finding that species with a variable rather than a fixed number of broods per year also delay their passage, possibly because they are free to attempt more broods [24]. Comparable results were also found in Oxfordshire on the British Isles [25].

This picture of advancements and delays in post breeding migration timing, being dependent on the species, seems to be consistent (at least) all over Europe, but the assumption of a rather simple division between advancing long distance migrants and delayed short distance migrants is not supported generally at other places [14]. While in most European Studies more species show a delay in post breeding migration timing [14,26], some studies like the one in southern Baltics clearly showed different trends at different time periods [27] and at the autumn passage on the Kola peninsula in Northern Russia the number of advances was much the same as the number of delays [28].

Despite the self-evident assumption that those birds advancing their autumn departure might benefit from an earlier arrival, an earlier onset of breeding and an earlier onset of post breeding moult [29], no marked relationship between timing in autumn and timing in the preceding spring has consistently been found [14].

2.2.3. Migration Routes and Wintering Areas

Results gained over more than a century of bird ringing enable us, at least in some regions with sufficient data, to detect possible changes in the migration routes and in the position of the wintering quarters. Birds marked with a small coded ring at the breeding grounds and recovered later outside the breeding season enable insights into the position of various areas used by the birds through the year as well as insights into the changes of the positions of these areas. Presumably wintering grounds and other areas used by birds during the non-breeding season like moulting areas or stopover sites during migration will change in the same way as changes of the breeding range have been described above. Generally, it can be expected that in regions with less severe winters migration routes will be shortened or that migration behaviour even will be reduced to zero. There is much evidence for a selection pressure towards earlier arrival at the breeding grounds for many bird species. Besides that, positions of wintering areas will also change when areas become unsuitable due to environmental changes. This may be true especially for birds wintering in areas endangered by desertification such as the Sahel Belt in Africa or parts of the Mediterranean Basin.

Studies available so far support these assumptions. Among 30 bird species investigated in Germany, 13 showed evidence of shorter migration routes, 11 showed evidence of a northward move of mean wintering latitude and 9 species showed increased numbers of winter recoveries within 100 km around the breeding place. Only a few species showed the opposite trend [30]. On a larger dataset of 66 species from the United Kingdom and Ireland it was found that 27 species showed increasingly northern wintering areas and 11 showed a northward move of the mean wintering latitude [31].

However, global warming might also lead to longer migration routes when breeding ranges are extended into higher latitudes and at the same time the wintering areas do not change much. For example, the European Bee-eaters showed a range expansion northwards and increased the intra-European part of their migration routes by up to 1000 km, but still winter south of the Sahara. Also the Black-Winged Stilt *Himantopus himantopus* expanded its breeding areas from the Mediterranean northward into France, Ucraine and Russia but still winters south of 40° latitude [1]. Evidence for increasing migratory activity also comes from White-rumped and Litte Swifts *Apus caffer* and *A. affinis* which colonise the Mediterranean area from the south, leaving these areas during non-breeding periods while they are resident in almost all of the rest of their African breeding ranges [32,33].

2.2.4. *Partial Migration*

Partial migration describes the widespread phenomenon of some birds of a population migrating, while others don't. This situation has been described as the turntable of migratory and sedentary behaviour which enables selection to favour either more migratory or more sedentary behaviour according to environmental conditions [34]. Increasing numbers of winter records of otherwise migratory bird species give evidence of the development of partial migratory populations in Europe and North America and presumably elsewhere [1]. The Central European Blackbird is a well known example of this phenomenon. It was once considered as a migrating thrush of European woodlands but in the early twentieth century it successfully started colonising human settlements and reduced migration to become the first entirely sedentary populations in recent decades [34,35].

2.2.5. *Eruptions*

The mass movements of parts of local populations, which may be directed but seldom are reversible, are commonly called eruptions or evasions. In less migratory species, with highly variable population sizes, living under highly variable food conditions such as tits in forest habitats and other boreal seedeaters, these eruptions occur repeatedly every few years. In a German Blue Tit population it has been shown that along with rising environmental temperatures, the numbers of eruptions have decreased remarkably [36]. While population size did not drop significantly, this observation (which might be a common phenomenon), may indicate a constant and improved food supply, making it unnecessary for parts of the population to emigrate.

2.3. Reproduction

2.3.1. *Onset of Breeding Period*

The reproduction of birds is influenced by weather and thus by climate change in many ways. It is known that temperature, precipitation and resulting food supply can trigger the start of breeding [37]. An analysis of the relationship between ambient temperature and time of the first egg laid showed that 45 out of 57 bird species advanced the time of the first egg, when temperatures were high. Therefore under current global warming it is not surprising that there are numerous studies indicating advancements in the onset of breeding in many species. With respect to migrating species the general advancement of arrival times in breeding areas has been mentioned above. Early breeding depends on fitness which stems from the availability of food insects which in turn depends on early leafing and flowering of plants under elevated spring temperatures [37,38].

Based on data from the British nest record scheme, for the period 1971–1995, Crick et al. [38] found significant trends towards earlier laying dates for 20 of 65 species analysed, with only one species having a delayed breeding date. The shift of the 20 species advancing their laying dates averaged 8.8 d. These species could neither be assigned to distinct migration strategies nor to ecological or taxonomic groups and comprise early and late breeders as well as long distance migrants and residents. Similarly, Tree Swallows *Tachycineta bicolor* throughout North America advanced their laying dates by up to nine days between 1959 and 1991 [39] and advancements of laying dates of six and nine days were also found in the German Great and Blue Tits *Parus major* and *P. caeruleus* between 1970 and 1995 [40]. Based on Danish bird ringing data of Arctic Terns *Sterna paradisaea*, A.P. Møller and colleagues reported an advancement of the ringing dates of chicks by 18 d during a 70 a period. This was explained by an increase in mean temperatures in April and May [41]. These are only few examples out of a long list of reports which in most cases indicated homologous trends.

2.3.2. *Length of Breeding Period*

As discussed briefly above, not only is the earlier onset of breeding beneficial, but it also may lead to an extension of the breeding period. In species with high nest predation rates, longer breeding periods can offer more time for replacement clutches or species might successfully raise more than one brood per season. Calculated durations of the stay of 20 migrating bird species at their breeding grounds, from passage data on the island of Heligoland, showed an average increase over a decade of 2.2 d [14]. A prolongation of the breeding period has also been shown in Reed Warblers *Acrocephalus scirpaceus* in Poland [42]. Between 1970 and 2006 the peak of egg laying advanced 18 d but the end of the breeding season did not change. Replacement clutches, in cases of nest failure, were produced in early years by 15% of breeding pairs while in recent years 35% of failing pairs started a second, third or up to a fifth laying attempt. For example, evidence for an increase in second broods (those are broods following a successful brood in the same season) comes from German Swifts: during the past few years Swifts have arrived at their breeding grounds earlier than before, have delayed post breeding migration [43,44] and have increased the number of second broods [45]. Also, correlations between weather, food availability and multiple broods per season have been shown in a series of studies on various bird species [46–49].

2.3.3. *Breeding Success*

Earlier arrival at breeding sites and earlier onset of egg laying in many bird species means also larger clutch sizes since there is a link between the length of daylight and the clutch size with clutches produced earlier often containing more eggs [50]. In a 30-year study of Reed Warblers breeding in Southern Germany the median of the date of the first egg advanced 15 d and the mean clutch size increased by about 0.5 eggs [51]. A similar relationship between onset of breeding, mean clutch size and breeding success can be found in Southern German Collared Flycatchers *Ficedula albicollis* (Fig. 2). However,

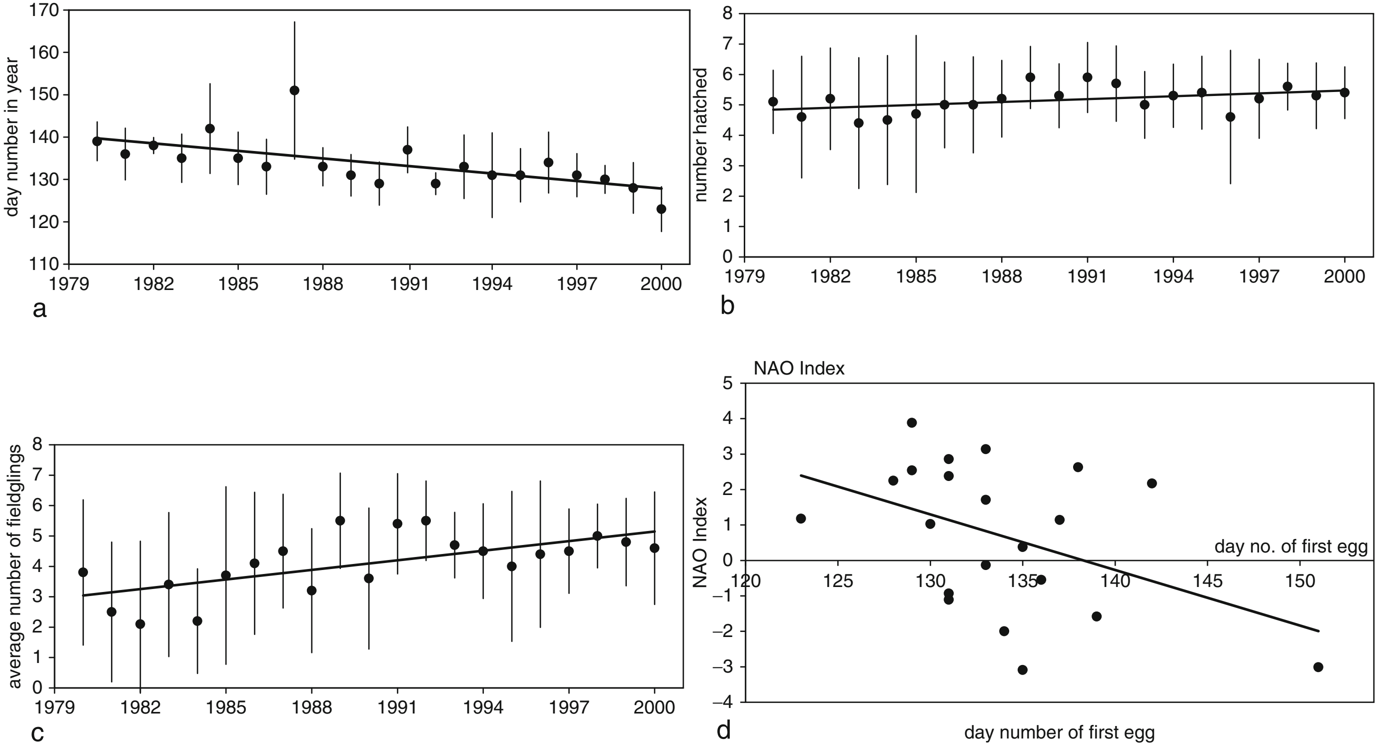

FIGURE 2 Date of first egg (a; day numbers counted from January 1), hatching success (b; average number of young hatched) and fledging success (c; average number of young fledged) of Collared Flycatchers *Ficedula albicollis* in a southwestern German study area. R^2 and ANOVA probabilities $>F$: a – 0.40, <0.003; b – 0.21, <0.04; c – 0.42, <0.002. Data from Renz, Dallmann and Braun, Analysis by Peintinger and Fiedler. (d) shows the correlation between the date of the first egg (day number in year) and the NAO Station based annual index (NAO Index Data provided by the Climate Analysis Section, NCAR, Boulder, USA, [18]); $R^2 = 0.19$, ANOVA probability $>F$ is 0.047.

reduced post fledging survival may prevent those populations from growing even when more young are produced. Capercaillies *Tetrao urogallus* in Scotland advanced the onset of breeding but suffer from a drop in breeding success, presumably due to seasonal changes in the insect supply for the chicks [52].

Optimal food supply of the young in the nest is crucial for reproductive success. Since timing of breeding as well as of moulting and migration is always a trade-off between multiple environmental and physiological requirements, phenological processes as induced by global warming may desynchronise. Marcel Visser, Christiaan Both and others presented a textbook example for this with Pied Flycatchers and Great Tits in Europe [53,54]. In nine Dutch study areas rising spring temperatures over the last 40 a, were connected with an advance of leafing and of the spring development of caterpillars of an abundant moth species (*Operophtera brumata*). These caterpillars form the most important food for nestlings of Pied Flycatchers and Great Tits and the birds aim to synchronize their breeding in a way that the caterpillar peak matches the time of highest food requirement for the nestlings. This is the time shortly before fledging, when large chicks have to be fed by the adults. Both bird species advanced laying dates in recent years but for the Pied Flycatcher (a long-distance migrant wintering south of the Sahara and spending 2/3 of it's lifetime outside Central Europe), other factors seem to prevent them from advancing the breeding period to match the advancing hatching times of the caterpillars. As a consequence, nestlings miss the caterpillar peak and breeding success decreases. In areas where caterpillars hatch very early Pied Flycatcher populations dropped by up to 90% while in areas with less advancing caterpillar timing, decreases only reached up to 10%.

2.3.4. Sexual Selection

In the large majority of migrating bird species, pairs do not migrate together and males arrive some time earlier at the breeding grounds than females. This phenomenon called protandry has been assumed to be affected by sexual selection because males emerging first at breeding grounds can occupy better territories and hence enjoy a mating advantage [55–57]. However, arriving too early at a breeding ground is a risk because food supply and weather conditions might not yet be suitable. If warmer spring temperatures reduce the risk of arriving too early at a breeding site, changes in the relation of costs and benefits of early arrival should have a greater effect on the sex arriving first, which in the majority of cases is the male. Indeed, in Danish Barn Swallows during 1971–2003, males advanced their arrival significantly while females did not [57]. It has also been shown that species with stronger female choice showed greatest advancements in arrival times which is in accordance with the assumption that early arrival of males is favoured by female choice [58,59].

In Blackcaps breeding in southwestern Germany and wintering either 1800 km southwest in Portugal and Spain or 1000 km northwest in the United Kingdom and Ireland, it has been shown that earlier arrival is not only related to a higher breeding success but also drives assortative mating among mates with comparable timing which drives evolution especially rapidly in one direction [60]. Birds wintering at higher latitudes not only face shorter distances to return to the breeding grounds but also experience a daylight-night-regime which triggers their circannual rhythms and accelerates pre-breeding migration, gonadal development and the onset of breeding [61,62].

3. CONCLUSION

The Ecology of birds can clearly serve as an indicator of climate and global change. Almost all aspects in the life cycle of birds, that have been regarded so far, show recent changes that can be linked to environmental changes. It is not surprising that birds show a high potential to adapt even complex behaviour such as breeding or migration to changing environments – either through evolutionary mechanisms acting on the genetic basis of behaviour or through available phenotypic plasticity. Ever since very early bird species evolved on earth 200 Ma ago, birds have had to cope with floating continents, rising and eroding mountains, ice ages and other massive environmental changes. A high degree of agility and mobility might have helped birds to adapt better to new conditions than other organisms might have done.

This is not to say that there is no conservation concern behind the reactions of birds to climate change. Some of the studies presented above clearly give evidence of problems that birds might face when they need to adapt their behaviour to rapid environmental and climatic changes. It is very likely that among bird species there will be winners and losers resulting from the current climate and global change and it might also be that the rate of losers will be high and extinctions of bird species will reach a level exceeding extinction rates seen in earlier times in bird's evolution. Since birds are easy to observe, are present in all parts of the world and are objects of interest to many people, they are ideal flagships to observe the consequences and the impacts of future environmental changes on organisms and on ecosystems.

REFERENCES

1. W. Fiedler, in: P. Berthold, E. Gwinner, E. Sonnenschein (Eds.), Avian Migration, Springer, Berlin, 2003, pp. 21–38.
2. J.F. Burton, Birds and Climate Change, Helm, London 1995.
3. A.T. Hitch, P.L. Leberg, Conservation Biology 21 (2007) 534–539.
4. M. Luoto, R. Virkkala, R.K. Heikkinen, Glob. Ecol. Biogeogr. 16 (2007) 34–42.
5. C.D. Thomas, J.J. Lennon, Nature 399 (1999) 213.
6. A. Townsend Peterson, M.A. Ortega-Huerta, J. Bartley, V. Sánchez-Cordero, J. Soberón, R.H. Buddemeier, D.R.B. Stockwell, Nature 416 (2002) 626–628.

7. N. Lemoine, H.-G. Bauer, M. Peintinger, K. Böhning-Gaese, Conserv. Biol. 21 (2007) 495–503.
8. R. Kinzelbach, B. Nicolai, R. Schlenker, J. Ornithol. 138 (1997) 297–308.
9. B. Huntley, R.E. Green, Y.C. Collingham, S.G. Willis, Climate Atlas of Breeding Birds in Europe, Lynx Editions, Barcelona, 2007.
10. M.B. Araúja, C. Rahbek, Science 313 (2006) 1396–1397.
11. F.A. La Sorte, F.R. Thompson, Ecology 88 (2007) 1803–1812.
12. P. Berthold, Naturwiss. Rundsch. 51 (1998) 337–346.
13. E. Lehikoinen, T.H. Sparks, M. Zalakevicius, in: A.P. Møller, W. Fiedler, P. Berthold (Eds.), Birds and Climate Change, Elsevier Science, London, 2004.
14. O. Hüppop, K. Hüppop, Proc. R. Soc. Lond. B 270 (2003) 233–240.
15. T.H. Sparks, F. Bairlein, J.G. Bojarinova, O. Hüppop, E.A. Lehikoinen, K. Rainio, L.V. Sokolov, D. Walker, Glob. Change Biol. 11 (2005) 22–30.
16. C. Parmesan, Glob. Change Biol. 13 (2007) 1860–1872.
17. M. Ahola, T. Laaksonen, K. Sippola, T. Eeva, K. Rainio, E. Lehikoinen, Glob. Change Biol. 10 (2004) 1610–1617.
18. J.W. Hurrell, Y. Kushnir, M. Visbeck, Science 291 (2001) 603–605.
19. P.P. Marra, C.M. Francis, R.S. Mulvihill, F.R. Moore, Oecologia 142 (2005) 307–315.
20. L.V. Sokolov, M.Y. Markovets, A.P. Shapoval, G.Y. Morozov, Zool. Zhurnal 78 (1999) 1102–1109.
21. N. Saino, T. Szep, M. Romano, D. Rubolini, F. Spina, A.P. Møller, Ecol. Lett. 7 (2004) 21–25.
22. O. Gordo, J.J. Sanz, Glob. Change Biol. 12 (2006) 1993–2004.
23. O. Gordo, L. Brotons, X. Ferrer, P. Comas, Glob. Change Biol. 11 (2005) 12–21.
24. L. Jenni, M. Kéry, Proc. R. Soc. Lond. Ser. B-Biol. Sci. 270 (2003) 1467–1471.
25. P.A. Cotton, Proc. Natl. Acad. Sci. 100 (2003) 12219–12222.
26. T.H. Sparks, C.F. Mason, Ibis 146 (2004) 57–60.
27. L.V. Sokolov, M.Y Markovets, Y.G Morozov, Avian Ecol. Behav. 2 (1999) 1–18.
28. A. Gilyazov, T.H. Sparks, Avian Ecol. Behav. 8 (2002) 35–47.
29. H.Q.P. Crick, T.H. Sparks, Nature 399 (1999) 423–424.
30. W. Fiedler, U. Köppen, F. Bairlein, in: A.P. Møller, W. Fiedler, P. Berthold (Eds.), Birds and Climate Change, Elsevier Science, London, 2004.
31. A. Soutullo, Dissertation, University of East Anglia, Norwich, 2003.
32. D.W. Snow, C.M. Perrins, Birds of the Western Palearctic, Oxford University Press, Oxford, 1998.
33. J.E. del Hoyo, A. Elliott, J. Sargatal (Eds.), Handbook of the Birds of the World, Lynx Editions, Barcelona, 1999.
34. P. Berthold, Bird Migration: A General Survey, Oxford University Press, Oxford, 2001.
35. H. Schwabl, J. Ornithol. 124 (1983) 101–116.
36. W. Winkel, M. Frantzen, J. Ornithol. 132 (1991) 81–96.
37. C.M. Perrins, Acta XIX Congr. Int. Ornithol. 1 (1988) 892–899.
38. H.Q.P. Crick, C. Dudley, D.E. Glue, D.L. Thomson, Nature 388 (1997) 526.
39. P.O. Dunn, D.W. Winkler, Proc. R. Soc. Lond. B 266 (1999) 2487–2490.
40. W. Winkel, H. Hudde, J. Avian Biol. 28 (1997) 187–190.
41. A.P. Møller, E. Flensted-Jensen, W. Mardal, J. Anim. Ecol. 75 (2006) 657–665.
42. L. Halupka, A. Dyrcz, M. Borowiec, J. Avian Biol. 39 (2008) 95–100.
43. M. Peintinger, S. Schuster, Vogelwarte 43 (2005) 161–169.
44. W. Gatter, Vogelzug und Vogelbestände in Mitteleuropa, Aula, Wiebelsheim, 2000.

45. E. Kaiser, Vogelwelt 125 (2004) 113–115.
46. M. Gucco, G. Malacarne, G. Orecchia, G. Boano, Ecography 15 (1992) 184–189.
47. J. Valencia, C. De la Cruz, J. Carranza, Etología 8 (2000) 25–28.
48. S. Verhulst, J.M. Tinbergen, S. Daan, Funct. Ecol. 11 (2003) 714–722.
49. S.F. Eden, A.G. Horn, M.L. Leonhard, Ibis 131 (2008) 429–432.
50. L. von Haartman, Proc. Int. Ornithol. Congr. 14 (1967) 155–164.
51. T. Schaefer, G. Ledebur, J. Beier, B. Leisler, J. Ornithol. 147 (2006) 47–56.
52. R. Moss, J. Oswald, D. Baines, J. Anim. Ecol. 70 (2001) 47–61.
53. M. Visser, A.J. van Noordwijk, J.M. Tinbergen, C.M. Lessells, Proc. R. Soc. Lond. B 265 (1998) 1867–1870.
54. C. Both, S. Bouwhuis, C.M. Lessells, M.E. Visser, Nature 441 (2006) 81–83.
55. R. Thornbill, J. Alcock, The Evolution of Insect Mating Systems, Harvard University Press, Cambridge, 1984.
56. M. Andersson, Sexual Selection, Princeton University Press, Princeton, 1994.
57. A.P. Møller, Glob. Change Biol. 10 (2004) 2028–2035.
58. D. Rubolini, F. Spina, N. Saino, Behav. Ecol. 15 (2004) 592–601.
59. C.N. Spottiswoode, A.P. Tøttrup, T. Coppack, Proc. R. Soc. Lond. B 273 (2006) 3023–3029.
60. S. Bearhop, W. Fiedler, R.W. Furness, S.C. Votier, S. Waldron, J. Newton, G.J. Bowen, P. Berthold, K. Farnsworth, Science 310 (2005) 502–504.
61. P. Berthold, S.B. Terill, Ringing Migration 9 (1988) 153–159.
62. T. Coppack, F. Pulido, M. Czisch, D.P. Auer, P. Berthold, Proc. R. Soc. Lond. B 270 (Suppl. 1) (2003) 43–46.